TITLE: LABORATORY EXPERIMENTS TO SIMULATE CO_2 OCEAN DISPOSAL **DATE:** May 1998

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I. ABSTRACT

OBJECTIVES: The primary objective of this investigation is to obtain experimental data that can be applied to assess the technical feasibility and environmental impacts of oceanic containment strategies to limit atmospheric emissions of fossil carbon dioxide (CO_2) from coal and other combustion systems. These strategies exploit the very large carbon storage capacity of the deep ocean. In a typical system, CO_2 extracted from a combustor is liquefied and transported to the deep ocean (to circumvent the slow natural CO_2 exchange that occurs in the upper layers of the ocean) via a submerged conduit and discharged, usually as a jet. Hydrodynamic instability induces break-up of the jet into droplets which will be buoyant at depths above 3,000 m. Dissolution of the rising droplets may be hampered by a solid hydrate film that forms on the surface of the droplets. The complex mechanisms of liquid CO_2 jet break-up, droplet dispersion and agglomeration, and dissolution in the deep ocean environment are not well-understood. The present investigation seeks to address several major deficiencies by the conduct of two categories of laboratory tests which will: (1) characterize size spectra and velocities of the dispersed CO_2 phase in the near-field of the atomized jet; and (2) estimate rates of mass transfer from single rising droplets of liquid CO_2 encased in a thin hydrate shell. The former tests will employ a Phase Doppler Particle Analyzer (PDPA) as the principal diagnostic while the latter will monitor droplet shrinkage by means of close-up video and image analysis.

SIGNIFICANCE TO FOSSIL ENERGY PROGRAM: The U.S. Department of Energy is promoting development of advanced technologies for recovery, reuse, and disposal of CO_2 from coal-fired power stations. The objective of this program is to identify alternatives which can supplement more cost-effective means of CO_2 control, such as efficiency improvements, energy conservation, and fuel switching. Given the limited reuse options for CO_2, commercial-scale recovery systems may need to be integrated with a disposal technique that will ensure long-term containment. Analyses performed to date have identified the deep ocean as the leading candidate repository for CO_2. These studies, however, have been hampered by a poor understanding of the behavior of liquid CO_2 effluent in the deep ocean. To this end, the present investigation will obtain data on CO_2 jet instability and droplet dispersion, coalescence, and dissolution that can be applied to the development and validation of predictive models to estimate the term of CO_2 sequestration, perform (ocean) environmental hazard assessments, and devise injection methods that ensure rapid dissolution and, hence, long-term containment of the CO_2 from the atmosphere.

II. ACCOMPLISHMENTS (HIGHLIGHTS)

- A new high-pressure water tunnel has been developed to investigate buoyant liquid CO_2 droplet dissolution under deep ocean conditions.
- A PDPA was designed and procured to perform measurements of liquid CO_2 droplet spectra and velocity in water.
- Joint research projects were initiated with the University of Bergen, Norway, and NIMC, Japan, to develop diagnostics for future field tests of CO_2 ocean disposal and to investigate an alternative process to contain CO_2 in the deep ocean.
- Experiments to characterize size spectra and velocities of liquid CO_2 jets under conditions simulating the deep ocean are ongoing.
- The facility was modified to reduce flow unsteadiness in the liquid CO_2 delivery system that complicated interpretation of data.
- An additional set of low and high ambient pressure tests have been initiated to clarify breakup of transitional and turbulent jets; results are relevant to deep ocean discharge of liquid CO_2.

III. ARTICLES AND PRESENTATIONS

With G.C. Nihous, "On the Effectiveness of Oceanic Containment Strategies Applied to Anthropogenic Carbon Dioxide," in *IONICS* (special issue for the International Chemical Congress of Pacific Basin Societies), No. 242, pp. 73-77, 1995.

"Laboratory Experiments to Simulate CO_2 Ocean Disposal," in *Proc. First Joint Power & Fuel Systems Contractors Conference*, U.S. Dept. of Energy, Pittsburgh, PA, 1996.

With H. Teng, C.M. Kinoshita, and G.C. Nihous, "The Effect of Hydrate Formation on CO_2 Jet Instability," *Prepr. Pap., Amer. Chem. Soc. Div. Fuel Chem.*, **41**, No. 4, pp. 1447-1451, 1996.

With H. Teng and C.M. Kinoshita, "Dispersion of CO_2 Droplets in the Deep Ocean," presented at ICCDR-3, The Third International Conference on Carbon Dioxide Removal, Boston, MA, USA, 9–11 September 1996, also in *Energy Convers. Mgmt*, **38**, No. 10–13, pp. 319-324, 1997.

With G.C. Nihous, "Rig Techniques and Experiments," invited paper presented at the 4th Expert Workshop–Practical & Experimental Approaches, Oct. 29-30, 1996, Tokyo, Japan, also in *Ocean Storage of Carbon Dioxide: Workshop 4–Practical and Experimental Approaches* (W. Omerod, ed.), pp. 37-48, IEA Greenhouse Gas R&D Programme, Cheltenham, UK, 1997.

With R.P. Warzinski, P.D. Bergman, and G.D. Holder, "The Effect of CO_2 Clathrate Hydrate on the Ocean Disposal of CO_2: A Review of DOE-Sponsored Research," 213th ACS National Meeting, San Francisco, CA, 13–17 April 1997.

With E.E. Adams, D.S. Golomb, and H.J. Herzog, "The Design of Pilot Scale Releases of CO_2 into the Deep Ocean," *Proc. 32nd Intersociety Energy Conversion Engineering Conference*, Vol. 3, pp. 2042-2047, AIChE, New York, 1997.

With G.C. Nihous, "Sequestering Carbon Dioxide in the Deep Ocean," accepted for presentation at the 17th Congress of the World Energy Council, 13-17 September 1998, Houston, TX.

With E.E. Adams, M. Akai, L. Golmen, P.M. Haugan, H.J. Herzog, S. Masuda, and T. Ohsumi, "An International Experiment on CO_2 Ocean Sequestration," accepted for presentation at the 4th International Conference on Greenhouse Gas Control Technologies, 30 Aug. 1998, Interlacken, Switzerland.